PB90-134412

Use of Flexible Membrane Liners in Hazardous and Nonhazardous Landfills

(U.S.) Environmental Protection Agency, Cincinnati, OH

1989

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comp

PB90-134412

1. REPORT NO. EPA/600/D-89/234	2.
4. TITLE AND SUBTITLE The Use of Flexible Membrane Liners in Hazardous and Nonhazardous Landfills	5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert E. Landreth	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS USEPA/RREL/WMDDRD/MSWRMB/LTS 26 W. Martin Luther King Drive Cincinnati, OH 45268	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Risk Reduction Engineering Laboratory--Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Robert E. Landreth FTS: 684-7836 COMM: 513/569-7836

16. ABSTRACT

The U.S. Environmental Protection Agency (EPA) was mandated by the U.S. Congress to develop standards for the management of both hazardous and nonhazardous waste in a manner that would protect human health and the environment. Researcha nd experience indicate that a properly designed, constructed, and operated landfill can provide alternative to safely dispose of waste. Use of a double, composite flexible membrane liner (FML) has been found to best protect the surrounding environment. The discussion that follows relates to the current status of the FML.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 15
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA/600/D-89/234

THE USE OF FLEXIBLE MEMBRANE LINERS IN HAZARDOUS AND NONHAZARDOUS LANDFILLS

Robert Landreth
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio

The U.S. Environmental Protection Agency (EPA) was mandated by the U.S. Congress to develop standards for the management of both hazardous and nonhazardous waste in a manner that would protect human health and the environment. Research and experience indicate that a properly designed, constructed, and operated landfill can provide alternative to safely dispose of waste. Use of a double, composite flexible membrane liner (FML) has been found to best protect the surrounding environment. The discussion that follows relates to the current status of the FML.

FEDERAL REGULATIONS

Regulations for managing both hazardous and nonhazardous wastes are based on Federal legislation of EPA-developed rules/regulations, and on state promulgated laws and regulations. Our interest here is the Federal guidelines that concern FMLs in solid and hazardous waste landfills.

The Legislative process

Congressionally passed legislation is the result of hearings held by subcommittees in both the House and the Senate, of debate and compromise in each branch, and of final compromise between the groups. This has resulted in such legislation as the Solid Waste Disposal Act (1965); the Resource Recovery Act (1970); the Resource Conservation and Recovery Act (RCRA, 1976); the Comprehensive Environmental Response Compensation, and Liability Act (CERCLA, 1980); the Hazardous and Solid Waste Amendments (HSWA, 1984); and the Superfund Amendments and Reauthorization Act (SARA, 1986).

To implement the rules/regulations, EPA develops three types of documents to assist those who prepare and those who review RCRA permit applications. These are:

1. RCRA Technical Guidance Documents that present design and operating parameters or design evaluation techniques that generally comply with design and operating requirements and closure and post-closure requirements;

2. Permit Guidance Manuals that require applicants and permit writers to address the information that EPA seeks;

3. Technical Resource documents that summarize technologies and techniques that represent good engineering designs, practices, and procedures.

These documents are not regulations, they only provide guidance. EPA proposes draft documents and manuals; they are circulated to the appropriate industrial, academic, and governmental community for comments; and then they are finalized and released.

COMPOSITE LINERS

Waste is compacted atop a filter layer, followed in turn by a primary leachate collection and removal system (LCRS), a primary FML, a secondary LCRS, and a composite liner consisting of a FML and compacted low-permeability soil above the native soil foundation (Figure 1). A composite liner is one that consists of a synthetic polymer and compacted, low-permeability, natural soils such as clays. Although leachate leaking through a clay liner may undergo chemical reactions that reduce the concentrations of leachate constituents, clay liners have a higher hydraulic conductivity and greater thickness than do synthetic liners. Although liquid may diffuse through a properly installed synthetic membrane - one with no holes or punctures or seam defects - the diffusion rates are very low when compared with hydraulic flow rates through clays. A composite liner is favored for double-liner systems because of the relative impermeability of the two liner systems together. Because numerical simulations have indicated the superior performance of the composite system and because leachate collection and removal are maximized, new units with composite bottom liners or double composite liners are being installed or proposed.

THE FLEXIBLE MEMBRANE LINER

The synthetic landfill liners are made of polymers, i.e., natural or synthetic compounds of high molecular weight. FMLs may be constructed of different polymeric materials such as:

- thermoplastics--polyvinyl chloride (PVC);
- crystalline thermoplastics--high density polyethylene (HDPE), linear low density polyethylene (LLDPE);
- thermoplastic elastomers--chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE).

These synthetic compounds contain various admixtures such as oils and fillers added to aid in the manufacturing and durability of the liners.

The performance of the liner is dependent on several factors that must be considered in selecting the proper liner materials. For membranes with and without fabric reinforcement, there are tests for analytical properties (volatiles, extractables, ash, specific gravity, including thermal analysis); for physical properties, (tear resistance, hydrostatic resistance, seam strength, ply adhesion); and for effects of environment and aging (ozone

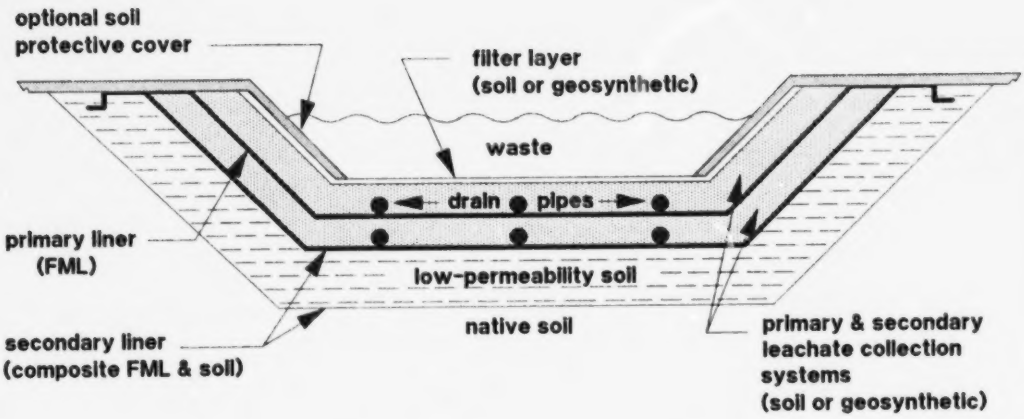

Figure 1. Schematic of a double composite liner.

cracking, environmental stress cracking, low temperature, tensile properties at high temperatures, dimensional stability, air-oven aging, water vapor transmission, water absorption, immersion in standard liquids and in waste liquids, soil burial, and outdoor exposure).

For example, in an ASTM test (E96) of the permeability of an FML, a sample of the membrane is placed on top of a small aluminum cup containing a small amount of water. When both are placed in a controlled humidity and temperature chamber, the humidity in the chamber is usually 20% and that in the cup, 100%, which sets up a concentration gradient across the FML. As moisture diffuses through the membrane, the liquid level in the cup is reduced. The rate at which moisture migrates through the membrane is moving is measured, and from that rate, a simple diffusion equation (Fick's first law) is employed to calculate permeability.

The manner in which the FML sheet is manufactured may affect its effectiveness. Although some manufacturing processes can cause high density polyethylene to crease and result in stress fractures, manufacturers have been working to resolve this problem and are now producing sheets of acceptable quality.

The mechanical properties of the FML should be fundamental design considerations. For example, uniaxial and biaxial tension tests indicate strains at which FML can fail when subjected to such tensions common in the field. The thermal coefficient of expansion of HDPE is three to four times that of other flexible membranes, and a 600-foot-long panel could grow 6 feet longer on a hot day.

Although a puncture test can be used to estimate how long an FML would survive in the field, they must be weighed along with other tests to determine survivability. For example, HDPE will have a very high penetration force and also have a very high brittle failure.

In a composite bottom liner system the FML must be at least 30 mils thick. This thickness is not suitable for all FML materials; the FML thickness is a function of the site specific design, installation/construction concerns, seamability, and long term durability. Taking these factors into account we recommend the following minimum thicknesses: PVC - 20/30 mil, CPE - 30 mil, CSPE-R - 36 mil and PE - 60 mil.

In addition to thickness, other key factors affecting selection of FML materials include chemical compatibility with waste leachate, aging and durability characteristics, stress and strain characteristics, the cost of installation, and water vapor/chemical permeation.

FML DESIGN ELEMENTS

When FMLs are employed in landfills, design elements, such as the following, must be considered: minimum technology guidance, stress considerations, structural details, and panel fabrication.

Technological guidance

To achieve EPA guidelines for minimum leakage, the liner should not leak more than an amount determined for each site's response action plan as determined by the owner/operator and the permit writer. The minimum thickness of an FML is set at 30 mil--or 45 mils if it will be exposed more than 30 days. Local variations can alter requirements, and upgrading requirements can greatly increase the cost. Increasing the liner thickness from 30 to 60 mils could double the per acre cost of the liner.

Stress considerations

Stress conditions must be considered for both the bottom and the side slopes of the landfill. For side slopes, the weight of the membrane itself and the weight of the waste must be reckoned with; because the FML must be able to support its own weight on the side slopes, the specific gravity, thickness, and yield stress of the FML and the friction angle must be known to calculate self-weight. For the bottom, localized settlement and normal compression must be considered. As waste settles in a landfill, a downward force acts on the primary FML, and a low friction component between the FML and the underlying materials prevents that force from being transferred to the underlying material and places tension on the FML.

As the waste is piled higher and higher, the normal load on the FML increases. Many of the newer materials (particularly LLDPE) will take a tremendous amount of normal load without failure; a biaxial tension applied to HDPE, however, will cause the materials to fail at a 16% to 17% strain, and the membrane may fail at a moderate settlement ratio.

Structural details

Anchorage, access ramps, collection standpipes, and penetrations are all structural details that warrant attention, especially in double liner systems.

In anchorage trenches (Figure 2), the FML can be ripped or pulled out. The pullout capacity for FMLs placed in various anchorage configurations (e.g., anchored horizontally or V-shaped) can, however be calculated.

Most facilities have access ramps to bring waste into the landfill. With double liner systems, the integrity of both liners must be maintained over the entire surface. During construction, such causes of failure as traffic-induced sliding, roadway considerations, and drainage must be neutralized. Traffic-induced sliding involves the weight of the roadway, the truck's breaking force, and the weight of the truck on the roadway. Tests and calculations can verify that the ramp subbase is stable under a load (ASTM test proposed), that the wheel loading will not damage the FML (ASTM proposed) and that the ramp will adequately drain surface water from the roadway (ASTM D4617 and D2434). In landfills that have a primary and a secondary LCRS, leachate penetrating the primary system and entering the secondary system must be removed. Vertical collection standpipes are used to access the primary leachate collection sumps (Figure 3). As waste settles, the standpipe can be affected by downdrag and the primary FML beneath can be punctured. ASTM proposed tests and ASTM 2435 can verify that downdrag-induced settlement of the standpipe will not cause the underlying FML to fail, can evaluate the

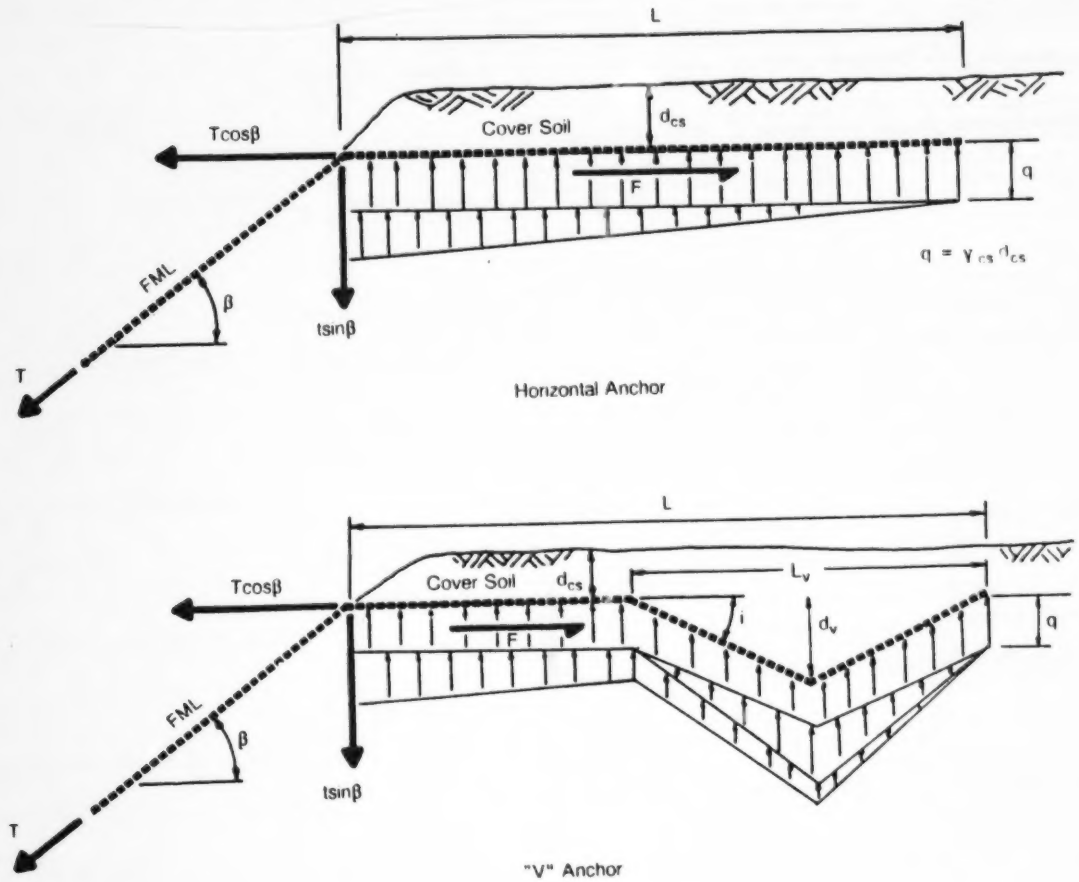

Figure 2. Anchorage trenches for FLMs.

potential downdrag forces acting on a standpipe, and can compare coatings (on the standpipe) for reducing these forces. Remedies could include coating the standpipe with viscous or low-friction coating or encapsulating it with multiple layers of HDPE. And flexible foundations could provide a more gradual transition and spread the distribution of contact pressures over a larger portion of the FML than would a rigid foundation.

The secondary leachate collection system is accessed by standpipes that must penetrate the primary FML. Although these penetrations may be rigid or flexible (Figure 4), flexible penetrations are preferred because these allow the pipe to move without damaging the liner.

Panel fabrication

The layout of FMLs in the landfill should be planned so that seams run up and down the slope, that the length of field seams is minimized whenever possible, and that no penetration of the FML should occur below the top of the waste.

CHEMICAL RESISTANCE OF FMLs

Because certain FML materials deteriorate over time when exposed to chemical constituents of leachate, the kind and quality of leachate that a site will generate must be predetermined and the liner material must be selected accordingly. Membranes are continually being improved while the waste streams are changing resulting in a need to evaluate the chemical resistance of the membrane for each specific site.

Representative leachate

When a landfill is proposed, a survey must be made to determine the quantity and quality of the waste to be received. Only then can a somewhat representative leachate be formulated.

Leachate is usually sampled directly from a sump at both active and closed landfills. Care must be taken not to agitate the sample during removal so its homogeneity will not be disturbed. Care must also be taken to sample municipal solid waste leachate under an inert atmosphere or it will begin to oxidize as soon as it leaves the sump. Samples should also be refrigerated to minimize volatile loss.

At some facilities, operators have placed coupons of the FML in the sump area to monitor leachate effects. This provides an excellent data base and allows compatibility problems to be discovered as they develop rather than after the liner fails.

Compatibility testing

EPA Method 9090 can be used for all geosynthetic materials used for liners and those used in leachate collection and removal systems. The results of Method 9090 have been verified with limited field data.

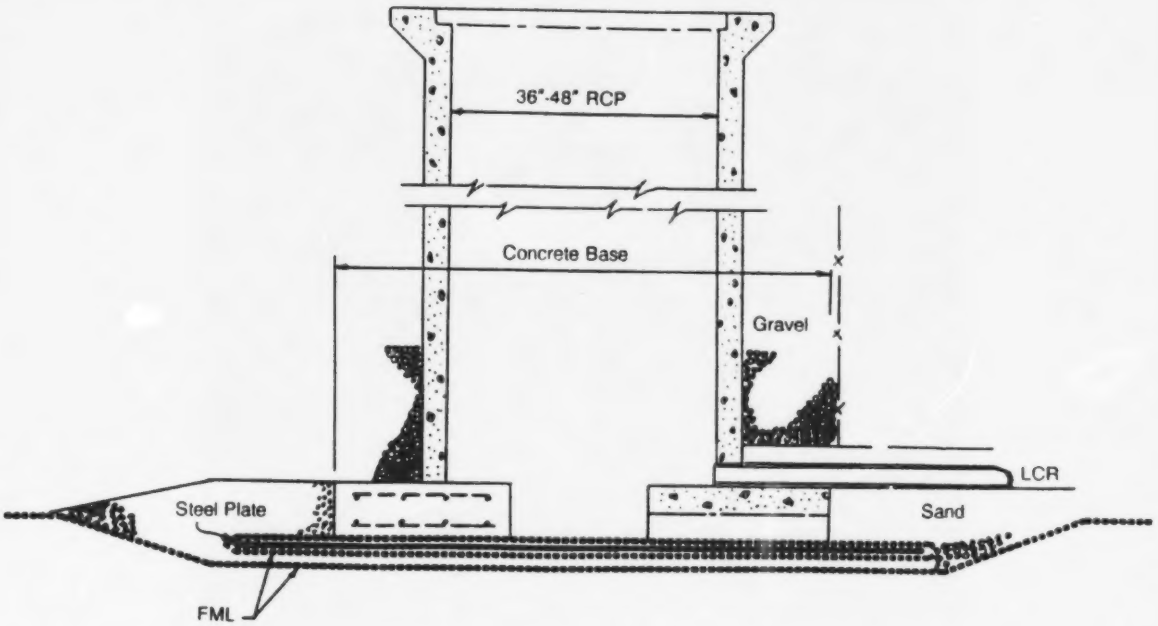

Figure 3. Details of vertical collection standpipe/drain.

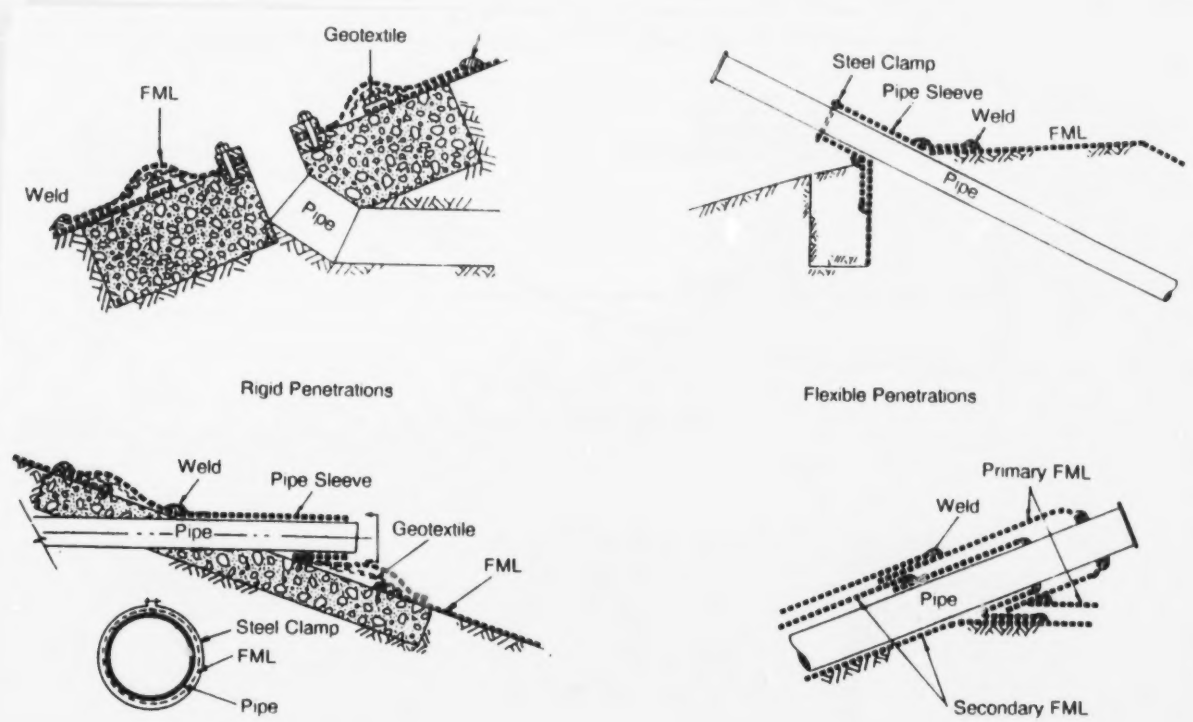

Figure 4. Details of rigid and flexible penetrations of FMLs.

In the test, the geosynthetic is immersed in the leachate for 120 days at two different temperatures. Every 30 days, samples are removed and evaluated for changes in physical properties. Among the chemical compatibility tests are those for hardness, volatile loss, specific gravity, tear resistance, water absorption, modulus of elasticity, thickness, length, width, tensile at yield and break, elongation at yield and break, etc. Physical property tests, which must be designed for different FMLs include those for puncture, thickness, transmissivity, grab tensile/elongation, abrasive resistance, burst strength, etc.

Natural drainage materials used in the landfill should also be tested to ensure that the leachate will not cause them to dissolve or form a precipitant that might clog the system. Moreover the natural material must retain its permeability characteristics and its ability to support the waste unit when exposed to leachate.

EPA grants no blanket approvals for any liner material--each material must be tested individually and be selected on the basis of site-specific conditions. To aid in interpreting chemical compatibility tests, EPA has developed a software system based on data from many chemical compatibility tests: the Flexible Membrane Liner Advisory Expert System (FLEX).

CONSTRUCTION QUALITY ASSURANCE FOR FMLs

The five steps that ensure quality construction for FMLs are: 1. responsibility and authority, 2. construction quality assurance (CQA) personnel qualifications, 3. inspection activities, 4. seam sampling strategies, and 5. documentation.

Responsibility and authority

Because an FML may be manufactured by one company, fabricated by another, and installed by a third, various people have responsibilities within the construction process. These can include engineers who generally design the components and prepare specifications, manufacturers who fabricate the FML, and contractors who perform the installation. The recent growth in the FML industry makes it necessary to exercise care in selecting firms with proven experience in all aspects of their operation.

CQA personnel qualifications

The CQA officer should be a professional engineer or equivalent with sufficient practical, technical, and managerial experience to understand the assumptions made in the design of the facility and the installation requirements of the chosen geosynthetic. Because not many have this experience, some firms assign (but do not bill for) an engineer-in-training to work with the trained CQA on the job to develop field expertise.

Inspection

Inspectors should be aware of the damage and defects FMLs can suffer during shipping, storing, and placement. For example, high crystalline FML panels fabricated at the factory rather than on-site must not be folded when shipped. White lines indicating stress will develop.

The bed on which the FML is to be placed must be examined to ensure it is adequately compacted; free of rocks, roots, water, and desiccation cracks; and free from a herbicides that may react witn the membrane.

Only after each panel is examined for and been found free of defects can it be placed in the landfill, with care taken to minimize sliding.

Inspection must determine that there is a firm foundation beneath the seam and that the FML is clean. Any defective seam must be bounded by areas that pass fitness structure tests; this entire bounded area must be repaired by a method agreed to in advance and must pass a careful visual inspection.

Sampling strategies for seams

Sampling frequency criteria can be continuous (100%), judgmental, and statistical. The continuous tests may be visual, destructive, and nondestructive.

All seams must be visually inspected. Then when a new seamer begins to work, when a seaming operation begins, when a new factory extrusion rod is used, or when adjustment is made to the equipment, a destructive test is used, i.e., a sample is cut from the seam when the seaming operation begins. The type of nondestructive tests used depends on the kind of seam and the membrane polymer. For example, in an air lance test (used for PVC, CPE, and other flexible liner material), a low pressure blast of air is focused on the edge of the seam; if there's a loose bond, the air lance will pop the seam open. Other tests include a mechanical point stress test, a vacuum chamber test, and a pressurized dual seam test. Ultrasonic equipment can also be used in a variety of seam tests.

Judgmental-type tests involve a trained operator or CQA inspector making a reasonable assessment of seam strength when a visual inspection detects factors such as apparent dirt, debris, grinding, or moisture that may affect seam quality.

True statistical testing is not done on seams; there are no outlier criteria for statistical testing of seams. No failure is acceptable. In addition to a minimum of one destructive test per shift, a minimum of one sample should be cut from every 500 feet of seam or a minimum of one test per seam. Typically, two tests are done on a destructive sample: a shear test to measure the continuity of tensile strength in the membrane and a peel test to determine seam quality (Figure 5).

Documentation

Documents must be kept while the FML is placed, inspected, and tested. The placement log details the panel identity, subgrade conditions, panel conditions, and seam details for every panel placed. Inspection documents must be maintained on all repairs, test sites, etc. A geomembrane seam test log indicates the seam number, length, test methods performed, location and date of test, and person performing the test. When the FML is completely in place, an as-built record of the landfill construction should be available to provide reviewers with an idea of the quality of the work performed as well as where the problems occurred.

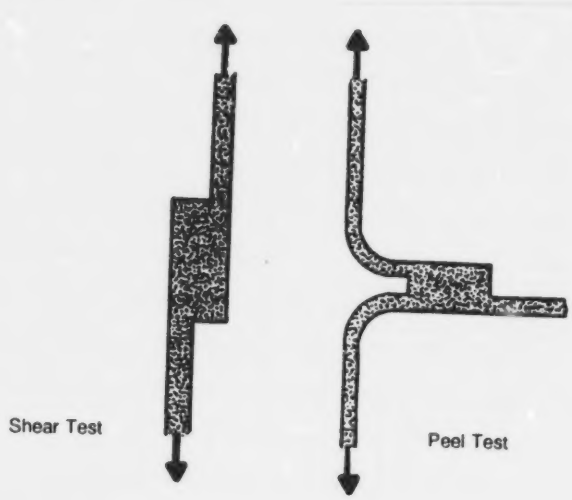

Figure 5. Seam strength tests.

LONG-TERM FML CONSIDERATIONS

The durability of FMLs is the major consideration in determining the total life of an FML-lined landfill. Under the ideal conditions of no sunlight, oxygen, or stress, a properly formulated, compounded, and manufactured FML will last intact indefinitely. Field conditions are, however, not ideal. Because it's not possible to directly measure an FML's life, the various physical, mechanical, and chemical factors that contribute to its degradation must be considered.

Oxidation

Oxidation, a major source of polymer degradation, occurs rapidly at high temperatures (over 200°F) and as FML is exposed to oxygen. Oxygen contact and sun-generated heat are minimized as the FML is covered by the filter layer.

Ultraviolet degradation

The process of photooxidation degrades all polymers, particularly at wavelengths between 315 and 380 nanometers. Blocking or screening agents, such as 2% to 3% carbon black, that are added during manufacture retard, but do not completely stop, degradation. Again, burying the FML beneath 6 to 12 inches of soil, within 6 to 8 weeks of construction, will prevent ultraviolet degradation.

Chemical degradation

All polymers swell when placed in water; this does not necessarily prevent them from functioning properly. Exposure to highly acid or alkaline leachates, especially at high temperatures, does, however, accelerate deterioration. Although most leachates are not acidic or basic enough to cause concern, the pH of the leachate must be considered in selecting an FML.

EPA's Method 9090, discussed earlier, and FLEX are available to test and access the physical changes that result from exposure to the chemicals in leachate.

Other degradation processes

The effect of high-energy radiation, which can break the molecular chains of polymers, is well established. What needs to be evaluated is the effects of low-level radiation, such as that from low-level radioactive hospital and laboratory wastes.

There is little evidence that biological activity, whether from bacteria, fungi, or insects or burrowing animals, can affect FML. Nor is there evidence that rapid changes in temperature or loss of plasticizers affect polymer strength or FML seam strength.

Stress-induced FML damage

Freeze-thaw and abrasion, two stress mechanisms that affect polymers are not problems if the liner is deeply buried. Freeze-thaw and abrasion, two stress mechanisms that affect polymers are not problems if the liner is deeply

buried. Not so with creep, however. Creep is the deformation of an FML over a long period of time under constant stress--stress on side slopes and at anchor trenches, sumps, protrusions, creases, etc. An FML material should be selected in which the anticipated actual stress will be less or significantly less than the yield stress, or the breaking strength of the scrim, or the stress at elongation, as determined by creep tests.

Stress cracking is defined as the brittle failure that occurs at a stress value less than a material's short-term strength. Stress presents potential problems with semi-crystalline FML's, particularly HDPE. This problem is currently of great concern because of the field problems occurring in exposed FML seam areas. The present stress tests are criticized as not being representative of field conditions, and work is ongoing to understand and solve this problem.

CONCLUSIONS

Landfill concerns can be solved by designing the site. Improved materials of construction and a good construction quality assurance/quality control plan can help ensure that the constructed facility will be as good or better than the paper design. Research and experience is improving our existing knowledge. The ideal secure facility is within our grasp.